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# SODIUM CARBONATE[1]

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## INTRODUCTION

Sodium carbonate, $Na_2CO_3$, more commonly known as soda ash, is the most important of the alkalies. Sulfuric acid is the only heavy chemical, other than common salt, produced in greater quantities. Following is the rank of soda ash in the chemical field:

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[1] The Bureau of Mines will welcome reprinting of this paper, provided the following footnote acknowledgment is used: "Reprinted from Bureau of Mines Information Circular 7212."

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Production of heavy chemicals in 1939, short tons
(From the Bureau of the Census)

| | | | |
|---|---|---|---|
| Salt | 10,003,448 | Caustic soda | 1,025,011 |
| Sulfuric acid | 7,711,487 | Chlorine | 490,256 |
| Soda ash | 2,960,722 | Salt cake | 337,243 |

Soda ash enters the market either as the natural product or as a manufactured derivative of common salt. Notwithstanding their common occurrence in closed basins of the Western States, natural sodas are produced at present by only four firms, all in the same California area, and satisfy only 4 percent of domestic demand for soda ash; soda ash made from salt supplies 96 percent of the requirements.

The impossibility in wartime of routing all westbound American shipping through the Panama Canal has curtailed Pacific Coast receipts of soda ash and increased the importance of local resources of natural carbonates. One of the most promising of these is the recently discovered trona (sodium sesquicarbonate) deposit 20 miles west of Green River, Wyo. Reserves are likely to run into hundreds of millions of tons, and the deposit probably could be worked by the room-and-pillar system of mining, like common salt or coal.

Raw materials necessary for manufacturing synthetic soda ash occur closely associated in many parts of the United States. Almost unlimited resources of salt in brines and in rock-salt deposits are located near limestone quarries in many areas. The limestone furnishes the carbon dioxide for the manufacture of soda ash and the lime for the recovery of ammonia used in one step of the process. Expansion of the industry to meet wartime needs depends chiefly on availability of trained labor, materials, and equipment necessary for the erection of additional units.

## DESCRIPTION

Normal sodium carbonate ($Na_2CO_3$, soda ash) is the most important member of the sodium carbonate group. As the common ash of commerce it is marketed in various degrees of purity based upon its content of sodium oxide, $Na_2O$. Nearly all manufactured and natural soda ash is refined and graded to an $Na_2O$ content of 58 percent, which is equivalent to a sodium carbonate content of about 99 percent.

There are several standard varieties of soda ash. Light ash is the product of the first calcination (see p. 24 ) and the most widely used. The density is 32 to 35 pounds per cubic foot. Extra-light ash, also called Fluf, or "fluffy soda," is a loose and bulky product having a density of about 23 pounds per cubic foot. This material is collected at the drying and finishing phase of the manufacturing process and is not available in large quantities. Dense ash results from longer calcination of the crude bicarbonate and comes in two weights - medium dense (50 pounds per cubic foot) and heavy dense (65 pounds per cubic foot). Dense ash is used chiefly by manufacturers of glass and as a carrier in the manufacture of dyes. Granular ash is coarse-grained and dense and comparatively dustless, and is used in foundries and glass works. Fused blocks of soda ash weighing 4 pounds each are used in metallurgy.

Monosodium carbonate or sodium bicarbonate, $NaHCO_3$, is next in importance as a sodium carbonate. Although sodium bicarbonate is the first product obtained in manufacturing soda ash from salt, the refined commercial product ordinarily is made by saturating a wet mush of soda-ash crystals with carbon dioxide or by redissolving and recrystallizing the original crude bicarbonate. Commercial bicarbonate is marketed according to the purity of the salt, principally as baking soda and as the chief ingredient in many forms of baking powder. It is widely used medicinally and in soap powders. It is used in fire extinguishers, ceramics, and gold and platinum plating, and to preserve food. The salt is generally regarded as a manufactured product, but occasionally it is found to occur naturally as a mineral, notably in Searles Lake, California.

Sodium carbonate decahydrate, $Na_2CO_3\text{-}10H_2O$, is usually made by cooling a properly concentrated solution of soda ash at a temperature below 32° C. and is used chiefly as a cleansing agent.

Sodium sesquicarbonate, $Na_2CO_3\text{-}NaHCO_3\text{-}2H_2O$, is the commonest form of naturally occurring sodium carbonate and is generally known as trona in the United States or as urao in Egypt, where it was first found and exploited commercially. It occurs as efflorescences on the shores of alkali lakes and is the first crystallization product in such lakes. Generally it is the salt from which natural soda ash is made. It may be manufactured by allowing a solution containing the proper proportions of soda ash and sodium bicarbonate to crystallize above 38° C. Crystals so formed are needlelike, uniform, and free-flowing, do not effloresce or deliquesce, and are readily soluble in water. The salt is used in laundries, textile manufacture, tanning, silk degumming, bath crystals, cream neutralization, and general cleansing.

Sodium carbonate monohydrate, $Na_2CO_3\text{-}H_2O$, is formed in small, rhombic crystals when a strong solution of sodium carbonate is cooled to 35° C.

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or when crystals separate from a saturated boiling solution. It is used in the manufacture of chemicals and cleaning and boiler compounds, in laundry and textile cleaning, and in photography.

Modified sodas are prepared by mechanically mixing soda ash, bicarbonate, and caustic soda in varying combinations and proportions. They are sold under various trade names and are used chiefly for industrial, restaurant, and household work involving cleansing of grease from milk bottles, cooking utensils, metals, and textiles.

Other sodium carbonates, as yet of no commercial value, are described by Hou.[4]

Sodium hydroxide, $NaOH$, commonly known as caustic soda, is not a carbonate but is closely connected with the soda-ash and alkali industry. It is the strongest[5] of the soda alkalies and is manufactured by reaction of a solution of soda ash with lime (calcium hydroxide) and also by electrolysis of a solution of common salt. Solid caustic soda is a white, opaque solid, very deliquescent and readily soluble in water, alcohol, ether, and glycerin. It has a molecular weight of 40.10, specific gravity 2.13, and melting point 318° C. Caustic soda is marketed in solid, flake, ground, powdered, liquid (water solution), and modified forms. The solid, flake, ground, and powdered caustic is sold in drums on a basis of 76 percent $Na_2O$, which is equivalent to approximately 98 percent $NaOH$; the principal impurity is sodium chloride. Liquid caustic is sold in tank cars in two concentrations: 47 to 49 percent $Na_2O$ and 70 percent $Na_2O$.

The following sales of caustic soda in 1939, by industries, have been reported:[6]

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[4] Hou, T. P., Manufacture of Soda: Am. Chem. Soc. Mon. Ser. 65, 1933, p. 30.

[5] Alkalinity is conveniently expressed by the pH scale, a series of numbers from 1 to 14, which represents the negative logarithm of the hydrogen-ion concentration in gram-ions per liter of solution. Pure water has a pH of 7, whereas solutions increase in acidity from 7 to 1. From 7 to 14, solutions increase in alkalinity. An equivalent weight of sodium bicarbonate in a liter of water solution has a pH of about 10.3; sodium carbonate, about 12.9; and sodium hydroxide, about 14.0.

[6] Chemical and Metallurgical Engineering, vol. 47, No. 2, January 1940, p. 70.

| Industry | Short tons |
|---|---|
| Soap | 100,000 |
| Chemicals | 165,000 |
| Petroleum refining | 84,000 |
| Rayon and cellulose film | 196,000 |
| Lye | 44,000 |
| Textiles | 44,000 |
| Rubber reclaiming | 18,000 |
| Purification of vegetable oils | 17,000 |
| Pulp and paper | 47,000 |
| Exports | 135,000 |
| Miscellaneous | 120,000 |
| Total | 970,000 |

Miscellaneous caustic-soda uses include the manufacture of paints, pigments, varnishes, synthetic perfumes, boiler compounds, and synthetic drugs. It is also used in softening water, bleaching, dyeing, printing, engraving, and lithography.

### Summary of commercial sodium carbonates

| Formula | Name | Mol. wt. | Sp. gr. | Melting point, °C. | Theoretical analysis | | |
|---|---|---|---|---|---|---|---|
| | | | | | $Na_2O$ | $CO_2$ | $H_2O$ |
| $Na_2CO_3$ | Soda ash, sodium carbonate. | 106.10 | 2.476 | 852 | 58.5 | 41.5 | 0 |
| $NaHCO_3$ | Sodium bicarbonate, baking soda, saleratus, acid sodium carbonate, Vichy salts, nahcolite. | 84.06 | 2.206 | Loses $CO_2$ at 270. | 36.9 | 52.4 | 10.7 |
| $Na_2CO_3$-$10H_2O$ | Sodium carbonate decahydrate, sal soda, soda crystals, washing soda, natron. | 286.15 | 1.458 | 34 | 21.7 | 15.4 | 62.9 |
| $Na_2CO_3$-$NaHCO_3$-$2H_2O$ | Sodium sesquicarbonate, trona, urao. | 226.18 | 2.112 | Decomposes before melting. | 40.8 | 29.6 | 29.5 |
| $Na_2CO_3$-$H_2O$ | Sodium carbonate monohydrate, crystal carbonate, thermonatrite. | 124.01 | 1.55 | Loses $H_2O$ | 50.0 | 35.5 | 14.5 |

## PRODUCTION

In early years the United States depended on imports for its supply of alkalies, but today's requirements are met almost entirely by domestic production. Imports of soda ash and its allied products have become insignificant; and, as shown on page 54, there are small but substantial exports. Most of the product is sold, but more than one-fourth is consumed in the producing plant, chiefly in the manufacture of caustic soda and sodium bicarbonate. Production from natural sources is increasing in the Western States, but even in 1939 it represented only 4 percent of the total for the country.

Salient statistics of the soda-ash industry in the United States, 1935, 1937, and 1939[1]

| | 1935 | | 1937 | | 1939 | |
|---|---|---|---|---|---|---|
| | Short tons | Value | Short tons | Value | Short tons | Value |
| Total production | 2,508,859 | - | 3,037,421 | - | 2,961,632 | - |
| Used in plant | 637,224 | - | 713,662 | - | 815,471 | - |
| Total sales | 1,871,635 | $28,424,750 | 2,323,759 | $33,768,770 | 2,146,161 | $32,871,016 |
| Sales by process of manufacture: | | | | | | |
| Ammonia-soda | 1,776,470 | 27,212,035 | 2,205,006 | 32,306,416 | 2,013,264 | 31,115,153 |
| Electrolytic[2] and natural[3] | 95,165 | 1,212,715 | 118,753 | 1,462,354 | 132,897 | 1,755,863 |
| Imports | 20 | 1,950 | 31 | 2,420 | 8 | 740 |
| Exports | 43,525 | 1,112,677 | 54,746 | 1,253,441 | 80,057 | 2,079,997 |

[1] Figures compiled from reports of the Bureau of the Census and Bureau of Foreign and Domestic Commerce.

[2] Electrolytic production for interplant transfer and not for sale.

[3] Sales of natural soda compiled by the Bureau of Mines are shown on page 8.

## Production of soda ash1/ in the United States in specified years, 1899-1939

| Year | Plants | Total production (short tons) | Plant consumption (short tons) | For sale | | |
|---|---|---|---|---|---|---|
| | | | | | Value | |
| | | | | Short tons | Total | Average per ton |
| 1899 | (2/) | (2/) | (2/) | 390,653 | $ 4,859,656 | $12.44 |
| 1904 | (2/) | (2/) | (2/) | 518,954 | 8,204,545 | 15.81 |
| 1909 | (2/) | (2/) | (2/) | 646,057 | 10,362,656 | 16.04 |
| 1914 | (2/) | (2/) | (2/) | 935,305 | 10,937,945 | 11.69 |
| 1919 | 18 | 1,507,424 | 473,944 | 1,033,480 | 31,195,149 | 30.18 |
| 1921 | 19 | 959,593 | 183,265 | 776,328 | 29,347,426 | 37.80 |
| 1923 | 14 | 1,707,987 | 449,207 | 1,258,780 | 32,427,166 | 25.76 |
| 1925 | 12 | 1,907,791 | 539,431 | 1,368,660 | 32,243,941 | 23.57 |
| 1927 | 12 | 2,037,808 | 571,429 | 1,466,379 | 29,939,291 | 20.42 |
| 1929 | 14 | 2,682,216 | 868,360 | 1,813,856 | 34,648,657 | 19.10 |
| 1931 | 15 | 2,275,416 | 766,737 | 1,508,679 | 22,492,943 | 14.91 |
| 1933 | 11 | 2,317,011 | 662,983 | 1,654,028 | 24,182,681 | 14.62 |
| 1935 | 16 | 2,508,859 | 637,224 | 1,871,635 | 28,424,750 | 15.19 |
| 1937 | 17 | 3,037,421 | 713,662 | 2,323,759 | 33,768,770 | 14.53 |
| 1939 | 17 | 2,961,632 | 815,471 | 2,146,161 | 32,871,016 | 15.32 |

1/ Includes production of electrolytic soda and natural sodas, if any (from reports of the Bureau of the Census).

2/ Data not available.

## Soda ash, produced for sale in the United States, 1921-39, by method of manufacture1/

| Year | Ammonia-soda process | | | | Electrolytic process and natural sodas | | | |
|---|---|---|---|---|---|---|---|---|
| | Plants | Short tons | Value | Average value per ton | Plants | Short tons | Value | Average value per ton |
| 1921 | 8 | 746,183 | $28,316,435 | $37.95 | 11 | 30,145 | $1,030,991 | $34.20 |
| 1923 | 6 | 1,225,027 | 31,413,210 | 25.64 | 8 | 33,753 | 1,013,956 | 30.04 |
| 1925 | 6 | 1,310,882 | 30,914,558 | 23.58 | 6 | 57,778 | 1,329,383 | 23.01 |
| 1927 | 6 | 1,402,728 | 28,645,404 | 20.42 | 6 | 63,651 | 1,293,887 | 20.33 |
| 1929 | 6 | 1,717,944 | 32,540,942 | 18.94 | 8 | 95,912 | 2,107,715 | 21.97 |
| 1931 | 7 | 1,422,614 | 21,079,187 | 14.82 | 8 | 86,065 | 1,413,756 | 16.43 |
| 1933 | 6 | 1,585,683 | 23,163,690 | 14.61 | 3 | 68,395 | 1,018,991 | 14.90 |
| 1935 | 9 | 1,776,470 | 27,212,035 | 15.32 | 7 | 2/ 95,165 | 1,212,715 | 12.74 |
| 1937 | 9 | 2,205,006 | 32,306,416 | 14.65 | 7 | 2/118,753 | 1,462,354 | 12.31 |
| 1939 | 10 | 2,013,264 | 31,115,153 | 15.46 | 6 | 2/132,897 | 1,755,863 | 13.21 |

1/ From reports of the Bureau of the Census.

2/ Electrolytic production in this year was for plant transfer only, not for sale.

## Production of natural sodium carbonates[1] in the United States, 1882-1940

| Year | Short tons | Value | Average value per ton |
|---|---|---|---|
| 1882 | 800 | - | - |
| 1893 | 3,100 | - | - |
| 1894-1915[2] | 7,489 | $74,412 | $10.07 |
| 1916 | 13,231 | 545,000 | 44.56 |
| 1917 | 21,743 | 895,602 | 41.19 |
| 1918 | 24,053 | 992,788 | 41.28 |
| 1919 | 28,638 | 869,901 | 30.38 |
| 1920 | 25,392 | 961,574 | 37.87 |
| 1921 | 17,400 | 602,800 | 34.64 |
| 1922 | 33,537 | 690,021 | 20.57 |
| 1923 | 35,440 | 751,850 | 21.21 |
| 1924 | 44,890 | 835,170 | 18.60 |
| 1925 | 45,910 | 922,760 | 20.10 |
| 1926 | 56,750 | 1,154,840 | 20.35 |
| 1927 | 67,240 | 1,253,352 | 18.64 |
| 1928 | 79,830 | 1,578,256 | 19.77 |
| 1929 | 102,930 | 1,916,632 | 18.62 |
| 1930 | 90,300 | 1,585,756 | 17.56 |
| 1931 | 78,530 | 1,223,544 | 15.58 |
| 1932 | 55,377 | 888,052 | 15.90 |
| 1933 | 70,461 | 918,295 | 13.03 |
| 1934 | 88,325 | 1,254,113 | 14.20 |
| 1935 | 93,230 | 1,173,003 | 12.58 |
| 1936 | 102,866 | 1,106,364 | 10.76 |
| 1937 | 104,711 | 1,191,485 | 11.38 |
| 1938 | 100,010 | 1,235,328 | 12.35 |
| 1939 | 124,743 | 1,528,810 | 12.26 |
| 1940 | 130,034 | 1,629,283 | 12.53 |

[1] Includes soda ash, bicarbonate, and trona; 1923-26 and 1930 also include sal soda.
Data derived from the following sources:
1882 - Geol. Surv. Min. Res., 1883.
1893 - Geol. Surv. Min. Res., 1893.
1894-1915 - Average for California compiled from California Mineral Production for 1928, State of California, Division of Mines, Bull. No. 102, p. 133.
1916-21 - Geol. Surv. Min. Res.
1922-40 - Bureau of Mines Mineral Resources and Minerals Yearbooks.
Except for 1924-27 and 1930, when a small amount of sal soda was reported from Green River, Wyo., all production was in California.

[2] Annual average.

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## CONSUMPTION AND USES

From earliest times soda ash has been used chiefly in glass and, directly or indirectly, in the manufacture of soap and cleaners. In the United States sales to the glass- and cleanser-manufacturing industries in 1939 took about 36.5 percent of the soda ash produced. About 49 percent was consumed in the manufacture of caustic soda for sale and plant use and in a number of other sodium chemicals, including sodium nitrate. Pulp and paper, aluminum, textiles, water softening, petroleum refining, and a number of miscellaneous processes took 11.6 percent of the total.

Estimated sales of soda ash to consuming industries are shown below, and insofar as data or estimates have been available, notations have been made to distinguish direct consumption of soda ash from consumption of causticized ash (caustic soda).

### Estimates of soda-ash consumption in the United States during specified years, 1929-39, short tons

(Based largely upon reports of the Bureau of the Census, Bureau of Foreign and Domestic Commerce, and Chemical and Metallurgical Engineering)

| Use | 1929 | 1931 | 1933 | 1935 | 1937 | 1939 |
|---|---|---|---|---|---|---|
| Glass[1] | 678,000 | 502,000 | 510,000 | 662,000 | 903,000 | 744,000 |
| Soap[1] | 80,000 | 100,000 | 90,000 | 115,000 | 165,000 | 195,000 |
| Soap[2] | 133,000 | 66,000 | 80,000 | 55,000 | 15,000 | 5,000 |
| Cleansers[3] | 125,000 | 112,000 | 94,000 | 120,000 | 140,000 | 137,000 |
| Caustic soda[4] | 787,000 | 684,000 | 659,000 | 650,000 | 722,000 | 786,000 |
| Chemicals[1] | 425,000 | 390,000 | 437,000 | 531,000 | 606,000 | 666,000 |
| Water softening[1] | 70,000 | 55,000 | 46,000 | 45,000 | 46,000 | 35,000 |
| Petroleum refining[1] | 18,000 | 7,000 | 7,000 | 8,000 | 9,000 | 11,000 |
| Aluminum production[2] | 36,000 | 26,000 | 13,000 | 18,000 | 43,000 | 48,000 |
| Textiles[3] | 40,000 | 31,000 | 34,000 | 48,000 | 38,000 | 43,000 |
| Pulp and paper[2] | 110,000 | 78,000 | 80,000 | 80,000 | 104,000 | 105,000 |
| Exports | 40,000 | 28,000 | 25,000 | 43,000 | 55,000 | 84,000 |
| Miscellaneous[5] | 140,000 | 196,000 | 242,000 | 134,000 | 191,000 | 102,000 |
| Total | 2,682,000 | 2,275,000 | 2,317,000 | 2,509,000 | 3,037,000 | 2,961,000 |

[1] Consumed in the product as soda ash.

[2] Converted to caustic soda by purchaser; consumed in purchaser's plant as caustic.

[3] Mixtures of soda ash and other alkalies derived from soda ash.

[4] Made and sold by soda-ash producer.

[5] About 69,000 tons soda ash used in making iron and steel in 1939.

Glass was made and blown into wares by the Egyptians more than 4,000 years ago, but origins of glass manufacture are lost in antiquity. Ancient glassmakers used trona from the Egyptian soda lakes and a pure silica sand from the mouth of the river Belus, near Mount Carmel, Palestine. Today the simple glasses are still composed principally of silica and alkali. Of the 744,275 tons of soda ash consumed in the glass-manufacturing industry in 1939, the Census Bureau reported the use of 120,339 tons in flat glass, 536,014 in container glass, and 87,922 in tableware.

The modern glass industry owes its existence to the development of methods for producing almost unlimited quantities of soda ash from common salt. Toward the end of the eighteenth century shortages in alkalies were developing, despite increasing shipments of natural soda into Europe by the Arabs via Spain. At this time potash was the cheapest and hence the dominant alkali and was a component of the ashes of both land and sea plants. The latter material, known as barrilla, was the source of most of the alkali used in the continental glass and soap industries until the Napoleonic era. The ashes of sea plants and wood ashes offered only limited supplies. Barrilla, composed principally of the carbonates, sulfates, and chlorides of sodium and potassium, was rapidly abandoned when the much purer Le Blanc soda became available, around 1793 in France and about 1823 in England.

Soda ash is 14 to 18 percent of the common glass batch; dense or heavy ash is preferred. Borax and sodium sulfate are the chief competitors of soda ash in the glass industry but actually represent only about 5 percent of the soda ash consumed in glass. The growing substitution of glass containers and utensils for tin cans and other wares during the war and the increasing consumption of glass building blocks, glass wool, fiber glass, and other specialties will further increase the demand for soda ash.

Soap. - Granulated soap, the chief direct outlet of soda ash in the detergents industry, is made from a hot soap solution to which soda ash has been added. On cooling, the water is taken up as water of crystallization in tiny crystals of sal soda, $Na_2CO_3 \cdot 10H_2O$, which form an intimate and integral part of the soap body. The mass is ground and screened to the desired size. Soap powders consist of approximately 20 percent soap, 40 percent soda ash, and 40 percent water. In 1939, 892,654,659 pounds of granulated soaps and soap powders were produced domestically, an equivalent of 178,600 tons of soda ash.

A common European practice in soap making, which recovers a very pure grade of glycerin, is to saponify the fats and oils with lime, $Ca(OH)_2$, instead of caustic soda. The lime soaps are then converted into soda soaps by double decomposition with soda ash. However, only one or two plants in the United States have used the lime-soap process, and the quantity of soda ash thus consumed is believed to be small.

Some soda ash also is used in making soap from fatty acids, such as oleic acid, a byproduct of the stearic acid industry, and rosin. The reaction is a neutralization in which carbon dioxide is given off in copious quantities, rather than a saponification, and no glycerin is produced. The more expensive caustic soda is not required in this reaction.

Since 1929 the trend in the soap industry has been to purchase caustic soda rather than to causticize soda ash, and only small quantities of ash are now causticized in the industry.

Cleansers. - Soda cleansers are made from combinations of soda ash and caustic soda to provide specified alkalinity. Such cleansers are used in the automatic washing of milk bottles, soft-drink bottles, restaurant dishes, and the like. A typical scouring powder based on soda ash has been analyzed as follows: Silica, 150 mesh, 73 percent; soda ash, 14 percent; soda soap, 9 percent; moisture, 4 percent.

Caustic soda. - In 1939, according to the Bureau of the Census, 523,907 short tons of caustic soda was made for sale by treatment of soda ash with slaked lime. The conversion required about 792,000 short tons of soda ash. In causticizing soda ash, a 20-percent solution of ash is heated to 85° C. with a slight excess of milk of lime and is agitated for 1 hour. After the resulting calcium carbonate has been allowed to settle, the solution (which contains about 12 percent sodium hydroxide) is decanted. The calcium carbonate sludge is washed twice, and the first wash is combined with the 12-percent liquor and evaporated to 50 percent NaOH. If solid caustic is desired, the evaporation is carried out completely in iron pots over a free flame. The causticizing process may be run either in batches or continuously. The yield is 88 to 89 percent theoretical.

Other sodium chemicals. - In 1939 about 660,000 short tons of sodium carbonate was used directly in the production of other sodium chemicals. Common salt, of course, is the basic source of nearly all manufactured sodium chemicals, for it enters into their production not only directly as salt but also indirectly as soda ash, caustic soda, salt cake ($Na_2SO_4$), sodium bicarbonate, sodium metal, or other derivatives. By far the chief salt derivative used in making other sodium chemicals is soda ash, owing (1) to its comparative cheapness and (2) to its ready reactions in double decompositions, either wet or dry. Common salt is five times cheaper than soda ash, but its use directly in the manufacture of other sodium chemicals is limited almost entirely to salt cake and electrolytic products, owing to the difficulty of disposing of the chloride part of the sodium chloride molecule.

The chief sodium chemical made from soda ash is sodium nitrate. Although the production of sodium nitrate was begun in the United States in December 1928, the output was estimated at 150,000 short tons in 1929 and by 1939 it had grown to 450,000 short tons, equivalent to 280,000 short tons of soda ash.

Important chemicals derived from soda ash

| Chemical | Soda ash required in 1939, short tons |
|---|---|
| Sodium nitrate | 280,000 |
| Sodium silicates | 195,000 |
| Sodium phosphates | 100,000 |
| Sodium chromates | 30,000 |
| Sodium thiosulfate | 20,000 |
| Sal soda | 11,000 |
| Sodium aluminate | 10,000 |
| Sodium silicofluoride | 4,000 |
| Sodium acetate | 3,000 |
| Sodium antimonate | 2,000 |
| Precipitated carbonates[1] including $CuCO_3$, $CaCO_3$ and $MgCO_3$, less than | 1,000 |
| Miscellaneous | 10,000 |
| Total | 666,000 |

[1] Does not include byproduct $CaCO_3$ such as that obtained by causticizing soda ash.

Water treatment. - In many industrial operations water is simply a cooling agent. Plants near the sea may make use even of salt water. But in other establishments - such as textile-dyeing works, laundries, or rayon plants - where water enters into the process, it must be free from certain dissolved salts that would react with soap or dyes. The most common dissolved impuritie are the bicarbonates, chlorides, and nitrates of calcium and magnesium. The bicarbonate of calcium $Ca(HCO_3)_2$ may be converted into the carbonate, $CaCO_3$, and be precipitated by lime. Magnesium bicarbonate also may be precipitated by lime, giving magnesium carbonate and calcium carbonate. The magnesium carbonate is somewhat soluble but can be converted into the highly insoluble magnesium hydroxide through further lime treatment. Magnesium chloride, if present, is converted also to hydroxide with lime, but this leaves calcium chloride in solution. By adding soda ash the latter is precipitated as calcium carbonate, the sodium chloride remaining in solution. Soda ash is used similarl for the removal of other calcium salts.

The increasing use of zeolites has reduced soda-ash consumption in this field. According to estimates of Chemical and Metallurgical Engineering, the amount of soda ash used in water softening decreased from 70,000 short tons in 1929 to 35,000 in 1939.

Petroleum refining. - In refining petroleum, soda ash is used in connection with the sulfuric acid treatment of some of the products obtained from the fractional distillation of crude oil. Sulfuric acid treatment improves the color of gasoline, decreases the sulfur content and improves the color and chemical stability of cracked distillates, and performs similar functions for other petroleum derivatives, the general effect being the removal of unsaturated hydrocarbons. After acid treatment the material is washed with water and then with dilute caustic soda or soda ash. In recent years it has been found expedient not to remove all the unsaturated hydrocarbons, and for this reason sulfuric acid treatment has been superseded to a considerable extent by other methods. Thus, in 1939 the Bureau of the Census reported that only 11,318 short tons of soda ash was consumed in petroleum refining, probably much of it for treatment of boiler water, in contrast with 18,441 short tons in 1929.

Aluminum. - Soda ash is causticized to caustic soda, and bauxite is added to a concentrated solution of the caustic. The alumina in the bauxite is converted to sodium aluminate: $2NaOH + Al_2O_3 \longrightarrow 2NaAlO_2 + H_2O$. Impurities are filtered off, and precipitated alumina from previous batches is added to the sodium aluminate solution, precipitating the alumina contained in the sodium aluminate. The alumina is filtered off, and a concentrated solution of caustic soda remains to repeat the cycle. On the average, about 150 pounds of soda ash is consumed per ton of bauxite treated. Much of the loss is in the formation of sodium silicate, and it is estimated that every pound of silica in the bauxite consumes an equivalent of 1 to 2 pounds of soda ash.

Soda ash used in textiles. - To mercerize cotton, the stretched cloth is treated with a 13.5-percent caustic-soda solution, which produces a fundamental transformation in the cotton fiber and enhances the luster and strength of the material. Soda ash is the source of the caustic.

The rayon industry required about 14,000 tons of soda ash in 1939. The ash is causticized, purified with celestite to remove traces of iron and certain other impurities, and used in the formation of the sodium cellulose xanthate from which the fibers are spun.

Soda ash is used to some extent in degumming silk, principally to soften the water and so prevent formation of soap curds, which would damage the silk.

Oils and greases are removed from woolen yarn, carpets, and piece goods by water solutions of soda ash and sodium silicate.

Pulp and paper. - In the soda-pulp process ground wood pulp (ordinarily from short-fibered woods such as poplar and beech) is digested in a concentrated solution of caustic soda, which dissolves lignin and other impurities, leaving crude fibrous cellulose. The cellulose may be used unbleached for inexpensive wrapping paper or bleached with chlorine for book, magazine, and stationery papers. Many paper-pulp plants in the United States make their own caustic soda and chlorine directly from common salt, whereas others, said to comprise more than half of the producers but capable of using less than half of the soda-pulp supply, buy soda ash and causticize it at the plant. Caustic soda is recovered at a certain point in the production cycle, and soda-ash purchases represent replacements of losses in recovery.

Soda ash is also used directly in certain newsprint deinking processes.

Miscellaneous uses. - The alkali has a number of uses in the reduction of certain ores. In the production of metallic chromium, chromite, $FeCr_2O_4$ is sintered with soda ash to form sodium chromate, which is converted to the dichromate by the addition of sulfuric acid and then fused with sulfur, yielding chromic oxide. The oxide may be reduced to chromium metal or its alloys by the usual methods.

Tungsten ores heated with soda ash yield sodium tungstate, which is treated in successive steps to produce metallic tungsten. Vanadium and ferrovanadium are made similarly through the formation of sodium vanadate.

In recent years considerable quantities of soda ash have been used in desulfurizing and dephosphorizing basic open-hearth steel, replacing manganese to some extent.

In one way or another soda ash is used in ceramic enamels, dyes, boiler compounds, munitions, paints, perfumes, fireproofing compounds, photographic supplies, matches, tanning, sugar refining, rubber, and many other processes and materials. Like salt and sulfuric acid, soda ash and its derivatives dovetail so intricately in the structure of modern civilization that life as we know it would be impossible without the alkali.

## HISTORY

Sodium carbonate has been known from earliest times. It is mentioned in the Bible, in records of the early Egyptians, and in other early writings. The oldest known production of natural soda was that from lakes of Lower Egypt, which dried during the summer, leaving an incrustation that was gathered and used as an article of trade. It has been known under many different names: The neter of the Old Testament; the nitrum, kali, and alkali of the Arabs; and as trona, urao, natron, soda ash, and barilla.

From the time of Christ until after the middle of the 18th century sea weeds and marine plants found along the shores of France, Great Britain, and

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Spain were burned and the ashes utilized, after treatment, for lyes, soap, and glass. These ashes contained but 3 to 40 percent soda ash; and some of the plants, especially the kelps, were eventually found to be more valuable for their content of potash and iodine. The ashes of certain shore marsh plants of Spain were considered best and were commercially known as barilla. They were shipped largely to France and England and were the chief source of alkali in these countries until Le Blanc soda became commercially available.

As the industrialization of Europe progressed, the demand for soda increased, until it became difficult to obtain adequate supplies. Accordingly, in 1775 the French Academy offered a prize for a practical and economical method of obtaining sodium carbonate from common salt, which was plentiful in France. A commercial process was developed in 1791 by Nicola Le Blanc, who used as raw materials salt cake (from salt and sulfuric acid), limestone, and coal.[7] Amid great acclaim a plant was erected at St. Denis, France; but, the plant and patents soon were confiscated by the French Revolutionary Government. Le Blanc died in poverty without having received the prize money and without having witnessed the success of his work.

In 1814 the Le Blanc process was set up in England on a small scale, but was not particularly successful. An improved plant erected at Liverpool in 1823, after giving away large quantities of soda ash to skeptical glass manufacturers, enjoyed almost immediate success. The process was established in Germany in 1843 and in Austria in 1851. A small plant was built in Wyoming in 1884 but was short-lived. The Le Blanc process found its greatest development in England.

Many other patented processes for the manufacture of soda ash from salt were tested in England and France during the 19th century. These included patents requiring ammonia and carbon dioxide, the use of which failed at first to have commercial value largely because of ammonia losses. From 1861 to 1864 two Belgian brothers, Ernest and Alfred Solvay, worked on patents by which the ammonia could be recovered. The first plant to use the Solvay process was erected at Couillet, Belgium, about 1866. In 1872 a large plant was established at Northwich, England, by Ludwig Mond. These were the forerunners of all the ammonia-soda or Solvay-process plants, which are now distributed over the world. The ammonia-soda process has almost entirely supplanted the Le Blanc process; and, except for a small but growing manufacture of soda ash from common salt by electrolytic processes and natural carbonates, the world's supply of soda ash is made by the process worked out by the Solvay brothers.

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[7] The reactions in the Le Blanc process are generally agreed to be:

1. $Na_2SO_4 + 2C \longrightarrow Na_2S + 2CO_2$.
2. $Na_2S + CaCO_3 \longrightarrow Na_2CO_3 + CaS$.

In the United States the early settlers first depended on wood ashes as a rew material for making soaps and glass. Later, alkalies were imported, chiefly from England. Small natural-soda plants erected on the Pacific coast were inaccessible to industry, and no soda manufactured by them was more than locally profitable until about 1885. In 1881 the Solvay Process Co. established an ammonia-soda plant in the United States near Syracuse, N. Y., and the first finished ash was made in about 1884. Other companies with plants situated conveniently to markets and basic supplies followed, and in 1939, 17 plants were producing soda ash in the United States.

## NATURAL SODAS

### Geologic Occurrence

Soda ash, $Na_2CO_3$, has never been found free in nature, and its existence in that state is improbable. It is so soluble in water, even at freezing temperatures (7.1 percent by weight), that, in evaporating saturated saline waters such as those of Searles and Owens Lakes in California, other salts are precipitated first. The normal order of deposition in Owens Lake is (1) trona ($Na_2CO_3$-$NaHCO_3$-$2H_2O$), (2) sodium sulfate, and (3) sodium chloride. Natron ($Na_2CO_3$-$10H_2O$), crystallizes only when evaporation has proceeded almost to completion.

Several theories are advanced to account for the soda alkalies brought into soda lakes. Crustal movements on the West coast, which have been in progress for millions of years, have been accompanied by a great deal of volcanic action, most of which is now dormant. Water percolating through the basic volcanic rocks and lavas has leached out alkaline soda salts and carried considerable quantities of them to closed basins, particularly the "Great Basin," an arid section lying between the Rocky Mountains and the Sierra Nevadas, where rainfall is scanty and streams have no outlet to the sea. Anoth theory that has been considered, particularly with regard to the Egyptian soda lakes, is the reduction of sodium sulfate by algae and the absorption of carbon dioxide from the air. A third possibility is the double decomposition between calcium bicarbonate and sodium sulfate or sodium chloride. Clarke[8/] states that probably all three processes occur to some extent.

### Domestic Deposits

Most of the alkali lakes and playas of the West contain sodium carbonate along with other saline matter and have been worked from time to time for their content of salts; but, with the exception of Searles and Owens Lakes, virtually all have been abandoned owing to inferior methods of recovery and distance from markets.

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[8/] Clarke, F. W., The Data of Geochemistry: Geol. Survey Bull. 770, 1924, pp. 218-260.

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There were four producers of natural sodium carbonates in 1940 - two at Owens Lake, Inyo County, and two at Searles Lake, San Bernardino County, Calif. The soda is a coproduct of boron and potash salts made from brines pumped from the lakes. When carbon dioxide is added to the brine, trona is precipiated, collected, and calcined and yields soda ash. Output of sodium carbonates from these sources rose to 130,034 short tons in 1940, an all-time record.

Many dry lakes, playas, and marshes in California contain sodium carbonate, but the alkali deposits of Mono Lake (Mono County), Owens Lake (Inyo County), and Searles Lake (San Bernardino County) are best-known. Mono Lake, because of its present inaccessibility, high altitude, and short solar-evaporation season, has never been exploited successfully. Conditions at these lakes have been described from time to time, notably by Chatard[9], Packard[10], and Gale[11].

Owens Lake was noted and its alkaline properties described as early as 1875-76[12]. The first operations on the lake were made possible when a railroad company, to obtain freight, became interested in the lake and obtained financial aid to establish a plant at Keeler[13], where, about 1885, steps were taken by the Inyo Development Co. to produce soda ash on a small scale. At that time the lake was a large body of water covering about 100 square miles and was fed by several streams, chiefly the Owens River. About 1912, another company, the Natural Soda Products Co., erected a plant a few miles south of Keeler.

Heavy demand and high prices during World War I encouraged establishment of other plants on Owens Lake. In 1917 the California Alkali Co., a subsidiary of the Great Western Electro-Chemical Co., erected a plant at Cartago, on the southwestern shore of the lake, and used solar ponds for evaporation of the brine. Lime burning provided carbon dioxide for precipitation of bicarbonate, and the product was calcined to yield both a light and a dense ash. These companies found ready soda-ash markets on the Pacific coast and in Japan up to the time of the Armistice of 1918. The plant of the Inyo Development Co. operated until 1920 and that of the California Alkali Co. until 1919. The latter plant and property resumed operations in 1923 but in 1924 were merged with another property, part of which was leased to the Natural Soda Products Co. The merger, known as the Inyo Chemical Co., produced soda ash and bicarbonate until about 1931.

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[9] Chatard, T. M., Natural Soda: Its Occurrence and Utilization: Geol. Survey Bull. 60, 1890, pp. 27-101.

[10] Packard, R. L., Natural Sodium Salts: Geol. Survey Mineral Resources of the United States, 1893, pp. 728-738.

[11] Gale, H. S., Salts Found at Owens Lake, Searles Lake, and Panamint Valley, Calif.: Geol. Survey Bull. 669, 1918, pp. 162, 164, 174; Salines in the Owens, Searles, and Panamint Basins, Southeastern Calif.: Geol. Survey Bull. 580, 1914, pp. 251, 323.

[12] Engineer Department, U. S. Army, United States Geographical Surveys West of 100th Meridian, 1889, pp. 189-190.

[13] Hirschkind, W., Alkali Lake Brines Supply Western Soda Producers: Chem. and Met. Eng., vol. 38, No. 11, November 1931, pp. 657-659.

In 1917 the waters of Owens River, the principal tributary of Owens Lake, were diverted to the Los Angeles aqueduct for the Los Angeles city water supply, causing gradual reduction in the size of the lake, which is now said to cover only about 17.2 square miles. By the summer of 1922 nearly all the bicarbonate had been precipitated in the lake and on the shores as trona. Changes in modes of operations were necessary. The Natural Soda Products Co. obtained its raw material by leaching deposits on the shores, wheread the California Alkali Co. (Inyo Chemical Co. after 1924) pumped equilibrium brine from the deeper part of the lake.

In 1926 the Kuhnert Syndicate of Los Angeles began to construct a plant at Bartlett, 10 miles south of Lone Pine on the west side of the lake, using the Kuhnert process to recover borax from brine, and began the manufacture of soda ash in 1928. In 1929 this concern became the Pacific Alkali Co., which in 1930 manufactured its first commercial borax and continued the output of soda ash and trona. It is reported that flood conditions on the lake forced the Natural Soda Products Co. to shut down for a time in 1938, 1939, and 1940. This company recently erected a new plant of 100 tons daily capacity on the east side of the lake south of Keeler, using a new method of manufacture not yet described.[14]

The Pacific Alkali Co. and the Natural Soda Products Co. were the only two plants operating at Owens Lake during 1940.

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[14] Bureau of Mines, Mineral Trade Notes: Vol. 10, No. 3, September 1939, p. 47.

Soda production at Owens Lake, Calif.[1]

| Firm | Operated | Soda products | Process of recovery |
|---|---|---|---|
| Inyo Development Co., Keeler, Calif. | 1885-1920 | 95 percent dense ash discolored by organic matter. | Trona crystallized in solar evaporating basins, washed, and calcined. Process inapplicable after 1920, owing to precipitation of trona as the lake dried up. |
| Natural Soda Products Co., Keeler, Calif. | 1912-40 | 97-98 percent dense ash discolored by organic matter. | 1912-22: Pumped brine from lake, carbonated with $CO_2$ from dolomite burning, washed and calcined the $NaHCO_3$ obtained. 1922-40: Leached lakeshore salts to obtain brine for carbonating. New unrevealed methods adopted in 1940. |
| California Alkali Co., Cartago, Calif. (as Inyo Chemical Co., 1924-31). | 1917-19<br>1923-31 | 99 percent light and dense ash discolored by organic matter. | 1917-19: Pumped brines from lake, concentrated in solar basins, carbonated liquors to $NaHCO_3$, washed, calcined to ash. 1922-31: Pumped equilibrium brine from deep part of lake; remainder process as above, but no solar evaporation. |
| Pacific Alkali Co., Bartlett, Calif. | 1928-40 | 99 percent dense ash, no organic matter. | Pumps brine from lake, carbonates to trona, washes, calcines at high temperature to burn out organic matter. |

[1] **Summarized mainly from** Hirschkind, W., Work cited in footnote 14.

Searles Lake, San Bernardino County, was discovered and located by John W. Searles in 1862 and relocated in 1873 as a borax deposit by Searles and Skillings.[15] It lies in a valley about 40 miles long and 25 miles wide between the Slate and Argus mountain ranges of the Sierra Nevadas, in the northern portion of the Mojave Desert. It is ovoid, and the central area of the main crusted deposit covers about 12 square miles, although the original lake covered 385 square miles. Before 1895 a small plant was operated intermittently to refine borax. From 1905-8 Searles Lake was again prominent through the proposal to establish a soda industry. After considerable agitation and litigation the California Trona Corporation was formed in 1908. It was succeeded in 1913 by the American Trona Corporation, which in 1926 became the present American Potash & Chemical Corporation, with a plant at Trona, on the northwestern edge of the lake, 185 miles northeast of Los Angeles. Extensive research into the nature of Searles Lake brines and methods of separation into its different constituents has resulted in remarkable expansion of the activities of this company. Production of potash and borax was begun in 1916, and from 1920-26 trona also was marketed. In 1934, besides its considerable output of borax and potash, soda ash and salt cake (sodium sulfate) were produced. A narrow-gage railroad 31 miles long connects Trona with the Southern Pacific Co. The company employs 900 to 1,000 workers. Another company, the West End Chemical Co., which since 1920 operated a plant at Westend, on the western shore of the lake, for the recovery of borax, began to manufacture soda ash in 1927. This material has now become the chief product of the company. Although there have been other efforts (notably those of the Burnham Chemical Co. from 1922 to 1929) to obtain sodium carbonates, borates, and potash from the brines of Searles Lake, the two companies mentioned are at present the only producers on the lake.

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[15] Hirschkind, W., Work cited in footnote 14.

At present Searles Lake has the general appearance of a frozen waste, the dried salts having formed an icelike crust over the surface. The porous salts are brine-soaked a few feet below the surface, and wells 10 to 20 feet deep yield adequate quantities of brine for pumping to the refineries. Until recently wells were never drilled deeper than 150 feet, which was the level at which mud appeared in the cores. Holes have now been driven to 300 feet and reveal additional reefs of salts, including almost pure sodium bicarbonate, interstratified with clay. Another new sodium mineral, burkeite ($Na_2CO_3$-$Na_2SO_4$), also was found in the cores.

Soda production at Searles Lake, Calif.

| Firm | Operated | Soda products | Process of recovery |
|---|---|---|---|
| American Potash & Chemical Co., Trona, Calif. | 1916-40 (trona sold 1920-26; soda ash 1934-40). | Trona, soda ash. | Brine pumped to plant, fractionally crystallized by phase rule methods, yielding trona, which is washed and calcined to soda ash. |
| West End Chemical Co., Westend, Calif. | 1920-40 (soda ash sold 1927-40). | Soda ash. | As above. |

Among other locations in California where natural soda deposits have been identified are Dorris and Dunsmuir, Siskiyou County; "Merced Bottoms," Merced County; Long Valley, Mono County; and Vernon, Los Angeles County.

Colorado. - Trona exists in quantity in the soda lakes of the San Luis Valley and to a small extent in other alkali lakes and areas.[16]

Nevada. - A natural soda deposit at Ragtown, Churchill County, described by Chatard[17] and Packard,[18] was utilized about 1868[19], and, according to Chatard, two sets of works were in operation in 1887. The process employed was crude, and with no convenient market the enterprise was abandoned. Some of the material was used as it came from the ground for the beneficiation of silver ores, but the greater part was subjected to a refining process and sold for other purposes.[20] Other deposits of sodium carbonates in Nevada have been noted near Hawthorne, Esmeralda County,[21] in Mineral County,[22] and analyses of the brines of the lakes near Ragtown, Ruby Valley, Antelope Valley, Humboldt Valley, Railroad Valley, Old Walker Lake, and Pyramin Lake have been cited by Wells.[23] These lakes also show sodium sulfate and other salts.

Oregon. - Abert, Summer, and Harney Lakes contain considerable sodium carbonate according to analyses cited by Wells.[24] Early investigations of most of these deposits showed the inadvisability of development at the time because of inaccessability of markets. A recent study[25] has again questioned the commercial feasibility of working the deposits.

Washington. - Active interest in deposits of sodium carbonate near Warden and Wilson Creek, Grant County, has been evidenced recently, and

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[16] Headden, Wm. Parker, Alkalies in Colorado (Including Nitrates): Colorado Agr. Coll., Agr. Exper. Sta. 239, May 1918, 58 pp.
[17] Chatard T. M., Work cited in footnote 10.
[18] Packard, R. L., Natural Sodium Salts: Geol. Survey Mineral Resources of the United States, 1893, pp. 728, 729.
[19] Wells, Roger C., Industrial Minerals and Rocks; 1937, p. 744.
[20] Williams, A. W., Jr. (compiler), Carbonate of Soda: Geol. Survey Mineral Resources of the United States, 1882, p. 601.
[21] Smock, J. C., and others, The Useful Minerals of the United States: Geol. Survey Mineral Resources of the United States, 1882, p. 772.
[22] Schrader, F. C., Stone, R. W., and Sanford, Samuel, Useful Minerals of the United States: Geol. Survey Bull 624, 1916, p. 198.
[23] Wells, Roger C., Sodium Salts in 1917: Geol. Survey, Mineral Resources of the United States, 1917, pp. 318, 319.
[24] Wells, Roger C., Industrial Minerals and Rocks: 1937, p. 742.
[25] Stafford, O. F., Preliminary Report upon Oregon Saline Lakes: Oregon State Dept. Geol. and Min. Ind., G. M. I. Short Paper 1, 1939.

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these deposits may ultimately be in commercial production. Analysis of the water of Soap Lake, Grant County,[26] also shows sodium carbonate. Omak Lake, in Okanogan County,[27] contains considerable quantities of sodium carbonate, but it is not utilized.

Wyoming. - A highly promising deposit of trona was discovered in 1938 and has been tested by core drillings made by the Union Pacific Railroad Co. about 30 miles west of the town of Green River, Sweetwater County. One trona bed lies at a depth of 1,500 to 1,600 feet and is 15 to 20 feet thick. It is reported that the nature of the deposit is such that it could be brought to the surface very cheaply by a shaft and by the use of the room-and-pillar system of mining.

Natural sodium bicarbonate in water of springs in Sweetwater County is said to have been known and used by the Mormon settlers as early as 1849,[28] and trona is said to be the predominating salt in Sweetwater Valley deposits near Independence Rock, 50 miles north of Rawlins, Sweetwater County.[29] The "Union Pacific Lakes," 13 miles due south of Laramie, and the Downey Lakes in Carbon County, 18 miles southwest of Laramie, at one time drew attention as producers of sodium carbonates. Soda works near Laramie produced material for glass from January to July 1885. In 1895, water containing sodium carbonate was found at Green River at a depth of about 125 feet. This water has served intermittently as the raw material for a small production of sal soda. In addition to being consumed locally, the water was evaporated by boiling, and the finely crystallized product was shipped for wider commercial use. No output has been reported since 1930, and recent efforts to revive the industry have been unsuccessful.

Other States. - Deposits of sodium carbonates in Arizona[30] have been reported at or near Montague, Chouteau County, and at Lost Lake in the Shonkin Sag, near Highwoods Mountains, Montana;[31] Antioch, Sheridan County, Nebr.;[32] Devils Lake, North Dakota;[33] and in the Valley of Deep Creek, Tooele County, Utah.[33], [34]

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[26] Wells, Roger C., Industrial Minerals and Rocks: 1937, p. 742.

[27] Steiger, George (analyst), Report of Work Done in the Division of Chemistry During the Fiscal Years 1891-92 and 1892-93: Geol. Survey Bull. 113, 1893, p. 113.

[28] Wells, Roger C., Industrial Minerals and Rocks: 1937, p. 744.

[29] Williams, A. W., Jr. (compiler), Carbonate of Soda: Geol. Survey Mineral Resources of the United States, 1882, pp. 602, 759; 1885, pp. 553-555.

[30] Economic Geology, Saline Lakes of the Mojave Desert Region: Vol. 21, No. 1, January-February 1936, p. 56.

[31] Reported to the Bureau of Mines by C. W. Morrison, Fort Benton, Mont.

[32] Wells, Roger C., Sodium Salts: Geol. Survey, Mineral Resources of the United States, 1919, p. 62.

[33] Wells, Roger C., Sodium Salts: Geol. Survey Mineral Resources of the United States, p. 319.

[34] Work cited in footnote 9.

## Methods of Recovery

The general method[35] of obtaining soda ash from waters of alkali lakes consists of (1) evaporation, (2) fractional crystallization, and (3) calcination of the hydrated product to anhydrous soda ash. Elaborations of the basic process have been introduced from time to time, depending on the constituents of the brines used and on the recovery of other salts, such as potassium chloride, borax, or sodium sulfate.

The brines of Owens Lake, California, now consist largely of sodium carbonate, sodium chloride, and a little sodium sulfate, bicarbonate, and borax. Before 1917 there was considerable sodium bicarbonate in the lake, but most of this was precipitated as trona from 1917-22, after the Owens River was diverted from the lake to supply water to Los Angeles. Before the river was diverted the alkaline brines were pumped into evaporating basins, and as evaporation proceeded a layer of trona crystallized out of the solution. When all the sodium bicarbonate in the brine had been used to form trona, the remaining liquor was returned to the lake and the process repeated until a 2-inch layer of trona had been built up. The trona was calcined to dense soda ash. The general practice at present is to precipitate the soda content of the brines as sodium bicarbonate, 60 to 70 percent of the sodium carbonate content being recovered in this way, as compared with about 30 percent by the old solar-evaporation system. (See table on p. 19.) Supplemental methods for recovery are discussed by Paul M. Tyler and A. T. Coons in Magnesium Compounds, Bromine, Calcium Chloride, Iodine, Sodium Sulfate, Borates, and Miscellaneous Salines: Bureau of Mines Minerals Yearbook 1940, Review of 1939, p. 1450.

Soda carbonates produced at Searles Lake are largely byproducts in the recovery of potassium chloride and borax. The Searles brines differ considerably from the Owens brines, for at ordinary temperatures the Searles waters are saturated with respect to at least five salts, including trona; therefore, if solar evaporation in large basins were attempted, instead of trona a useless conglomerate of five or more salts would crystallize in the basins. However, much research in phase-rule equilibria of the brines by W. E. Burke and Harald de Ropp[36] has solved the problem. Evaporation is carried out inside the plant in modified triple-effect evaporators at controlled temperatures, so that several salts, including borax, potassium chloride, potassium sulfate, trona, sodium sulfate, burkeite ($Na_2CO_3$-$Na_2SO_4$), and lithium salts, are separated and recovered. The trona is calcined to soda ash.

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[35] Very impure trona has been hauled directly from the trona reefs bordering Searles Lake and sold as a cheap alkali, but sales have been quite small.

[36] The phase studies are given in Teeple, J. E., Industrial Development of Searles Lake Brines: Am. Chem. Soc. Mono. Ser. 49, Chemical Catalog Co., Inc., New York, 1929.

## MANUFACTURED SODA ASH

Only two methods of manufacturing soda ash (excluding soda ash from natural sodas) are important today: (1) The Solvay or ammonia-soda process and (2) the electrolytic process, both of which use salt as a raw material.

The reactions in the ammonia-soda process are:

$$\left.\begin{array}{ll}1.\ \ NH_3 + H_2O \longrightarrow NH_4OH & \text{(reversible)} \\ 2.\ \ CO_2 + H_2O \longrightarrow H_2CO_3 & \text{(reversible)}\end{array}\right\}\ \text{Ammonia and carbon dioxide are bubbled into the vat.}$$

3. $NH_4OH + H_2CO_3 \longrightarrow NH_4HCO_3 + H_2O$.

4. Salt is added to the solution, precipitating sodium bicarbonate:
$NH_4HCO_3 + NaCL \longrightarrow NaHCO_3$ (precipitated) $+ NH_4Cl$.

5. The bicarbonate is calcined to soda ash:
$NaHCO_3 + \text{heat} \longrightarrow Na_2CO_3 + H_2O$.

6. The ammonia is recovered for reuse:
$2NH_4Cl + Ca(OH)_2 + \text{heat} \longrightarrow 2NH_3 + H_2O + CaCl_2$.

For economical operation soda-ash plants must be near salt deposits, either rock salt or (preferably) brine, and must have access to limestone deposits for carbon dioxide and lime. Fuel for calcination and recovery of ammonia also must be available. These conditions are fulfilled for existing plants, a list of which is given on page 34.

The first domestic plant using the ammonia-soda process was established near Syracuse, N. Y., in 1881 by the Solvay Process Co., shortly before the successful beginning of the natural soda industry on the Pacific coast. The Solvay Process Co. also has plants at Delray, near Detroit, Mich. at Hutchinson, Kans. (idle since 1918); and at Baton Rouge, La., established in 1935. Other alkali plants are those of the Michigan Alkali Co. at Wyandotte, Mich. (initial operation in 1892); the Mathieson Alkali Works, Inc., with one plant at Saltville, Va. (initial operation in 1893), and another at Lake Charles, La. (established in 1934); the Columbia Chemical Division, Pittsburgh Plate Glass Co., which began production of soda ash in 1900 at Barberton, Ohio; the Diamond Alkali Co., which began operations in 1910 at Fairport, Ohio; and the Southern Alkali Corporation, which started in 1934 at Corpus Christi, Tex. The southern plants represent the greatest expansion of the industry in 25 years and were established primarily to supply the newly developed glass, paper and pulp, and soap industries of the South. The new southern plants are on tidewater for export trade and have rail connections to the North, South, and West. Large deposits of salt and limestone or oyster shells are available as raw materials, as are also abundant sources of natural gas and fuel oil.

Electrolytic soda ash is made by passing an electric current through a cell containing a saturated solution of salt. Sodium hydroxide forms at the cathode, and when carbon dioxide is bubbled into the solution around the cathode, sodium bicarbonate is precipitated. The product is dried and calcined to produce soda ash. Three plants operated by the West Virginia Pulp & Paper Co. at Luke, Md., Tyrone, Pa., and Covington, Va., use this process and consume the soda ash and the chlorine byproduct in the manufacture of paper pulp.

The total investment in all of the soda-ash plants, including natural soda, is estimated at $125,000,000 to $150,000,000.

## FOREIGN TRADE

### Imports

In the United States, sodium carbonates were imported to a certain extent in early colonial times, but for making soap the colonists depended chiefly on lye leached from wood ashes. By 1869, however, imports of sodium carbonates had assumed considerable importance, and during that year imports of soda ash amounted to 65,674 short tons valued at $2,365,640. In 1883, the year before the first production of domestic soda ash, imports amounted to 161,863 short tons; but in 1884, when the first 12,230 tons were made at Syracuse, N. Y., imports had declined to 143,701 tons. Since that time imports have fluctuated greatly but are today limited largely to small quantities of special reagent-grade sodium carbonate. Before 1869 virtually all of the sodium carbonates imported came from English sources. In recent years most of the imported soda ash has come from the United Kingdom, but some has been received also from Japan and Germany.

## Soda ash and sodium bicarbonate imported for consumption into the United States, 1869-1939

(Compiled from reports of Bureau of Foreign and Domestic Commerce)

| Year[1] | Soda ash | | Sodium bicarbonate | |
|---|---|---|---|---|
| | Short tons | Value | Short tons | Value |
| 1869-78[2] | 81,591 | $3,104,193 | 5,344 | $303,706 |
| 1879-88[2] | 138,152 | 3,423,512 | 1,138 | 50,726 |
| 1889-98[2] | 130,404 | 2,791,820 | 1,270 | 37,873 |
| 1899-1908[2] | 13,356 | 233,860 | 100 | 5,362 |
| 1909-18[2] | 1,356 | 37,864 | 46 | 2,790 |
| 1919-28[2] | 1,527 | 44,317 | 31 | 1,872 |
| 1929 | 14,350 | 354,074 | 2 | 364 |
| 1930 | 2,588 | 63,699 | 7 | 897 |
| 1931 | 7 | 576 | 10 | 2,189 |
| 1932 | 15 | 1,079 | 48 | 1,281 |
| 1933 | 15 | 1,263 | 39 | 2,583 |
| 1934 | 71 | 4,726 | 4 | 209 |
| 1935 | 20 | 1,950 | 89 | 852 |
| 1936 | 44 | 3,886 | 239 | 4,945 |
| 1937 | 31 | 2,420 | 277 | 5,290 |
| 1938 | 20 | 1,565 | 146 | 14,335 |
| 1939 | 8 | 740 | 17 | 528 |
| 1940 | [3] | 74 | [3] | 21 |

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[1] 1869 to 1918 represent fiscal years; 1919-40, calendar years.

[2] Average.

## Soda ash and sodium bicarbonate imported for consumption in the United States, 1936-40, by countries

| Year | Country | Soda ash | | Bicarbonate | |
|---|---|---|---|---|---|
| | | Pounds | Value | Pounds | Value |
| 1936 | France | - | - | 110 | $ 17 |
| | Germany | 18,203 | $1,190 | - | - |
| | Japan | 634 | 27 | 567,707 | 4,643 |
| | Sweden | 3,416 | 411 | - | - |
| | United Kingdom | 66,668 | 2,258 | 9,788 | 285 |
| | Total | 88,921 | 3,886 | 577,605 | 4,945 |
| 1937 | France | - | - | 666 | 107 |
| | Germany | 13,180 | 1,033 | 814 | 38 |
| | Japan | 28,030 | 308 | 551,523 | 5,136 |
| | Sweden | 3,196 | 391 | - | - |
| | United Kingdom | 18,140 | 688 | 110 | 9 |
| | Total | 62,546 | 2,420 | 553,113 | 5,290 |
| 1938 | France | - | - | 312 | 70 |
| | Germany | 6,605 | 344 | 33,188 | 1,093 |
| | Japan | 760 | 30 | 56,161 | 885 |
| | Sweden | 1,656 | 120 | - | - |
| | United Kingdom | 31,276 | 1,071 | 150 | 12 |
| | Total | 40,297 | 1,565 | 89,811 | 2,060 |
| 1939 | France | - | - | 143 | 21 |
| | Germany | 3,369 | 281 | 80 | 30 |
| | Japan | 1,000 | 32 | 33,600 | 459 |
| | Sweden | 1,543 | 64 | - | - |
| | United Kingdom | 9,100 | 363 | 620 | 18 |
| | Total | 15,012 | 740 | 34,443 | 528 |
| 1940 | Hongkong | 400 | 26 | - | - |
| | Japan | 470 | 48 | 315 | 21 |
| | Netherlands | - | - | - | - |
| | United Kingdom | - | - | - | - |
| | Total | 870 | 74 | 315 | 21 |

## Exports

Exports of sodium carbonates and caustic soda from the United States are controlled entirely by the United States Alkali Export Association, Inc., of New York City, representing domestic producers. This association, formed in 1918, functions in accordance with the Webb-Pomerene law for the purpose of eliminating competition among American exporters in foreign markets. It exercises complete control over all matters connected with the exportation of soda alkalies, their price, shipment, distribution, exchange transactions, etc. Tonnage is supplied the association by the members upon a percentage-allocation basis, and each member receives the same unit price regardless of the tonnage furnished. The association acts as an independent body, initiating and completing all sales and shipping in its own name.

## Soda ash, bicarbonate, and sal soda exported from the United States, 1918-40

(Compiled from records of the Bureau of Foreign and Domestic Commerce)

| Year | Soda ash |  | Bicarbonate |  | Sal soda, etc. |  |
|---|---|---|---|---|---|---|
|  | Short tons | Value | Short tons | Value | Short tons | Value |
| 1918 1/ | 119,217 | $7,805,550 | (2/) | (2/) | 6,358 | $213,865 |
| 1919 | 50,481 | 2,656,608 | (2/) | (2/) | 5,563 | 178,285 |
| 1920 | 83,381 | 4,689,591 | 10,321 | $616,216 | 6,015 | 220,487 |
| 1921 | 17,521 | 850,369 | 5,852 | 307,138 | 5,177 | 204,616 |
| 1922 | 14,814 | 678,983 | 7,928 | 341,459 | 5,732 | 186,284 |
| 1923 | 14,512 | 729,704 | 8,467 | 387,861 | 6,112 | 179,006 |
| 1924 | 14,342 | 683,118 | 7,612 | 333,337 | 6,539 | 199,329 |
| 1925 | 16,190 | 775,478 | 8,649 | 350,585 | 6,696 | 195,329 |
| 1926 | 19,767 | 936,451 | 9,669 | 372,700 | 6,326 | 159,810 |
| 1927 | 20,401 | 977,414 | 9,144 | 338,155 | 6,371 | 163,675 |
| 1928 | 33,330 | 1,241,272 | 9,356 | 344,974 | (2/) | (2/) |
| 1929 | 38,992 | 1,340,544 | 9,474 | 357,027 | 6,209 | 189,581 |
| 1930 | 32,936 | 1,138,899 | 9,909 | 369,817 | 6,537 | 196,581 |
| 1931 | 27,639 | 857,714 | 9,355 | 330,239 | 4,529 | 125,607 |
| 1932 | 13,798 | 459,633 | 7,010 | 251,667 | 2,861 | 85,150 |
| 1933 | 28,441 | 749,704 | 7,468 | 245,729 | 1,976 | 60,504 |
| 1934 | 33,431 | 962,458 | 7,598 | 253,941 | 1,025 | 27,209 |
| 1935 | 43,525 | 1,112,677 | 6,739 | 227,396 | 1,143 | 26,196 |
| 1936 | 44,268 | 1,074,788 | 8,265 | 275,054 | 756 | 20,153 |
| 1937 | 54,746 | 1,253,441 | 9,635 | 306,830 | 1,040 | 25,190 |
| 1938 | 51,016 | 1,326,539 | 10,482 | 331,828 | (2/) | (2/) |
| 1939 | 80,057 | 2,079,997 | 15,557 | 504,976 | (2/) | (2/) |
| 1940 | 58,509 | 1,592,260 | 11,300 | 408,415 | (2/) | (2/) |

1/ Not recorded before 1918.

2/ Not reported separately.

## Exports of soda ash from the United States during 1918, 1929, 1933, and 1937
(Compiled from records of the Bureau of Foreign and Domestic Commerce

| | 1918 | | 1929 | | 1933 | | 1937 | |
|---|---|---|---|---|---|---|---|---|
| | Short tons | Value | Short tons | Value | Short tons | Value | Short tons | Value |
| Canada | 36,614 | $1,911,488 | 4,821 | $ 244,955 | 2,018 | $ 96,152 | 6,618 | $ 237,085 |
| Mexico | 2,329 | 140,918 | 6,661 | 192,483 | 7,846 | 219,985 | 16,130 | 361,381 |
| Belgium | - | - | - | - | 4 | 328 | 582 | 8,690 |
| Denmark | 195 | 15,881 | 267 | 12,392 | 154 | 5,661 | 502 | 5,956 |
| Finland | - | - | - | - | 24 | 1,191 | 79 | 3,296 |
| France | 150 | 13,043 | 10 | 557 | 9 | 556 | 10 | 621 |
| Germany | - | - | 4 | 280 | 5 | 259 | 263 | 3,014 |
| Italy | 94 | 5,678 | 1 | 40 | 4 | 297 | - | - |
| Netherlands | - | - | 536 | 30,193 | 23 | 1,614 | 1,502 | 19,565 |
| Norway | 3,644 | 280,265 | 25 | 1,389 | 71 | 2,101 | 44 | 2,748 |
| Spain | - | - | 37 | 1,716 | 2 | 114 | - | - |
| Sweden | 1,307 | 81,863 | 22 | 1,112 | 119 | 4,590 | 4,045 | 55,164 |
| United Kingdom | - | - | 200 | 12,415 | 303 | 20,049 | 417 | 31,005 |
| Argentina | 1,820 | 133,203 | 150 | 8,481 | 4,077 | 91,448 | 5,260 | 114,931 |
| Bolivia | 4 | 266 | (1/) | 25 | 1 | 39 | 96 | 2,348 |
| Brazil | 7,158 | 593,304 | 9 | 558 | 1,807 | 45,364 | 3,516 | 68,622 |
| Chile | 2,853 | 179,455 | 2,147 | 46,367 | 45 | 1,094 | 58 | 2,473 |
| Colombia | 371 | 29,330 | 166 | 7,210 | 881 | 23,878 | 226 | 7,874 |
| Ecuador | 92 | 6,934 | 3 | 268 | 25 | 658 | 45 | 1,343 |
| Perú | 373 | 32,004 | 123 | 4,868 | 14 | 503 | 595 | 11,215 |
| Uruguay | 200 | 12,337 | 23 | 1,456 | 255 | 5,532 | 766 | 16,492 |
| Venezuela | 802 | 56,958 | 75 | 3,196 | 70 | 2,486 | 778 | 21,093 |
| British India | 13 | 794 | 90 | 5,543 | 2,854 | 52,700 | 984 | 19,046 |
| China | 705 | 69,316 | 310 | 10,290 | 432 | 9,405 | 5 | 303 |
| Japan | 47,442 | 3,417,074 | 17,519 | 548,560 | 4,308 | 64,038 | 5,792 | 79,973 |
| Philippine Islands | 543 | 38,946 | 118 | 6,319 | 252 | 10,985 | 616 | 17,972 |
| Cuba | 5,214 | 178,487 | 4,326 | 146,757 | 1,364 | 41,575 | 2,202 | 61,480 |
| Netherlands East Indies | 498 | 45,753 | 282 | 6,813 | 300 | 4,736 | 1,692 | 26,385 |
| Australia | 5,668 | 476,287 | 155 | 6,439 | 332 | 9,462 | 484 | 18,609 |
| Other | 1,093 | 84,721 | 912 | 39,837 | 843 | 32,904 | 1,417 | 53,958 |
| Total | 119,217 | 7,805,550 | 38,993 | 1,340,544 | 28,442 | 749,704 | 54,746 | 1,253,440 |

1/ Less than 1/2 ton.

## TARIFFS

Soda ash was first made dutiable at 1/4 cent a pound by the Tariff act of 1883. The act of 1897 raised the duty to 3/8 cent a pound, but the act of 1909 restored it to 1/4 cent a pound, which continued until the act of 1913 placed soda ash on the free list. The duty of 1/4 cent a pound was again placed in effect by the act of 1922, and this rate was continued in the 1930 act.

Sodium bicarbonate is on the free list by the Tariff Act of 1930, but in earlier acts it paid a duty varying from 1-1/2 cents a pound, required by the act of 1883, to 1/2 cent a pound, required by the act of 1913.

Sal soda was made dutiable by the act of 1883 at 1/4 cent a pound. The rate was lowered to 1/8 cent by the act of 1894 but was reestablished at 1/4 cent by the act of 1930.

## PRICES

The larger soda-ash producers or their sales representatives annually publish a scale of prices for the ensuing year, and this minimizes annual price fluctuations. The close integration of many of the producers with respect to subsidiary manufacturers of glass, soap, and chemicals also tends to stabilize prices. Five roughly concentric price zones have been set up, extending from New York City to California. West coast (zone 5) prices are about 25 percent higher than zone 1 prices.

Soda-ash prices for a period of years and a description of the five zones (from the Oil, Paint, and Drug Reporter) follow:

Original from THE OHIO STATE UNIVERSITY

### Soda ash spot prices, carlots, at works, per 100 pounds
(From Oil, Paint, and Drug Reporter)

| | Dec. 26, 1914 | Dec. 30, 1918 | Dec. 30, 1929 | Dec. 25, 1933 | Dec. 27, 1937 | Dec. 29, 1941 |
|---|---|---|---|---|---|---|
| Dense ash (58 percent $Na_2O$): | | | | | | |
| Bags.......... | 1/$0.67-1/2-0.72-1/2 | $2.90-4.00 | $1.40 | $1.25 | $1.10 | $1.15 |
| Barrels....... | (2/) | 3.30 | 1.57-1/2 | 1.50 | 1.35 | 1.35 |
| Bulk.......... | (2/) | (2/) | 1.25 | 1.10 | .95 | .95 |
| Light ash (58 percent $Na_2O$): | | | | | | |
| Bags.......... | 3/ 0.57-1/2-0.62-1/2 | 2.00-2.25 | 1.34-1/2 | 1.23 | 1.05-1.08 | 1.05-1.13 |
| Barrels....... | (2/) | 2.55-2.75 | 1.67-1/2 | 1.50 | 1.35 | 1.35 |
| Bulk.......... | (2/) | (2/) | 1.17-1/2 | 1.05 | .90 | .90 |
| Extra-light ash (58 percent $Na_2O$): | | | | | | |
| Bags.......... | (2/) | (2/) | 1.34-1/2 | 1.23 | 1.08 | 1.05-1.13 |
| Barrels....... | (2/) | (2/) | 1.70 | 1.60 | 1.45 | 1.45 |
| Bulk.......... | (2/) | (2/) | (2/) | 1.05 | .90 | .90 |

1/ 48 percent $Na_2O$.
2/ Not quoted.
3/ 58 percent $Na_2O$ but sold upon basis of 48 percent $Na_2O$.

Original from THE OHIO STATE UNIVERSITY

The sales zones are:

Zone 1. - All northern United States east of the Mississippi River and north of the southern boundaries of Kentucky and Virginia, including also Davenport, Iowa, and St. Louis, Mo.; Louisiana, Mississippi, Alabama south of 31° parallel, Texas east of 100° meridian and south of 31° parallel, and Florida. In Maine, New Hampshire, and Vermont special local zone prices apply for shipments to various counties.

Zone 2. - Arkansas east of 93° meridian; Nebraska east of 98° meridian; Texas north of 31° parallel and east of 100° meridian (except Wichita Falls); Alabama, Louisiana, and Mississippi north of 31° parallel; Iowa (except Davenport), Georgia, Minnesota, Missouri (except St. Louis), North Carolina, South Carolina, and Tennessee.

Zone 3. - Kansas and Nebraska west of 98° meridian; Texas west of 100° meridian (including also Wichita Falls but excluding El Paso); North Dakota, South Dakota, Oklahoma, and Arkansas west of 93° meridian.

Zone 4. - El Paso, Tex.; Spokane, Wash.; Arizona, Colorado, Idaho, Montana, Nevada, New Mexico, Utah, and Wyoming.

Zone 5. - California, Oregon, and Washington (except Spokane).

The Bureau of Labor Statistics, United States Department of Labor, has compiled the following table of soda-ash prices:

Annual average of wholesale price quotations per 100 pounds of 58-percent $Na_2O$ light ash

| Year | Average price at works | Year | Average price at works |
|---|---|---|---|
| 1925 | $1.430 | 1934 | $1.230 |
| 1926 | 1.430 | 1935 | 1.230 |
| 1927 | 1.375 | 1936 | 1.230 |
| 1928 | 1.366 | 1937 | 1.157 |
| 1929 | 1.345 | 1938 | 1.050 |
| 1930 | 1.345 | 1939 | 1.050 |
| 1931 | 1.161 | 1940 | 1.050 |
| 1932 | 1.182 | 1941 | 1.050 |
| 1933 | 1.197 | | |

## THE INDUSTRY IN FOREIGN COUNTRIES

The first ammonia-soda plant, Solvay et cie, was established in Belgium in 1865, and the company rapidly founded other soda plants, more or less closely associated, on the Continent, in England, the United States, and Canada. This group, known as the Solvay Syndicate, largely controlled the international soda trade before World War I. The war forced considerable decentralization, however, and affiliated producers in the United States, Great Britain, and Soviet Russia withdrew. In the interbellum period of 1919-39 the syndicate was reorganized as the International Alkali Cartel, with many of its former members, and resumed control of the bulk of soda-ash production and sales on the European Continent. Germany undoubtedly is maintaining production of such plants as remain (1942) undestroyed in Austria, France, Italy, Poland, Spain, Romania, Czechoslovakia, and Yugoslavia.

Although Germany is the third largest producer of soda ash in the world and controls production in at least 10 other European countries, total production of soda ash by the Axis powers and the nations they control is less than that of the United States. According to available estimates, the soda-ash capacity of the United Nations is probably more than twice that of the Axis. The position of Japan is particularly insecure with respect to soda ash. The Japanese Empire is an emerging mountain chain where salt deposits have had little or no opportunity to form. Like many of the other raw materials required in Japanese industry, salt for soda-ash manufacture must be imported.

The following table indicates the approximate soda ash-producing capacity in the various countries before 1939. The estimates do not consider any damage to existing plants or any new plants built since 1939.

Estimated world capacity for producing soda ash[1]

| | Short tons | |
|---|---|---|
| United Nations: | | |
| United States | 3,500,000 | |
| United Kingdom | 1,500,000 | |
| Soviet Russia | 700,000 | |
| Canada | 40,000 | |
| British East Africa | 40,000 | |
| China | 20,000 | |
| British India | 20,000 | |
| Total | 5,820,000 | 5,820,000 |
| Axis-dominated nations: | | |
| Germany | 1,250,000 | |
| Netherlands | 500,000 | |
| Japan | 200,000 | |
| Italy | 100,000 | |
| Czechoslovakia | 90,000 | |
| Belgium | 80,000 | |
| Poland | 60,000 | |
| Austria | 45,000 | |
| Romania | 35,000 | |
| Norway | 18,000 | |
| Yugoslavia | 10,000 | |
| Total | 2,388,000 | 2,388,000 |
| Neutral nations: | | |
| Spain | 40,000 | |
| Switzerland | 33,000 | |
| Sweden | 13,000 | |
| Argentina | 4,000 | |
| | 90,000 | |
| Total | | 90,000 |
| World total | | 8,298,000 |

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[1] Based largely upon published reports of the Bureau of Foreign and Domestic Commerce.

## DOMESTIC PRODUCERS

| Name and address | Plant site |
|---|---|
| Natural Soda | |
| At Searles Lake, San Bernardino County, Calif. | |
| American Potash & Chemical Corporation,<br>Trona, Calif. | Trona, Calif. |
| West End Chemical Co.,<br>608 Latham Square Building,<br>Oakland, Calif. | Westend, Calif. |
| At Owens Lake, Inyo County, Calif. | |
| Natural Soda Products Co.,<br>405 Montgomery Street,<br>San Francisco, Calif. | Keeler, Calif. |
| Pacific Alkali Co.,<br>1206 Pacific Mutual Building,<br>Los Angeles, Calif. | Bartlett, Calif. |
| Manufactured Soda | |
| Ammonia-soda process | |
| Columbia Chemical Division,<br>Pittsburgh Plate Glass Corporation,<br>30 Rockefeller Plaza,<br>New York, N. Y. | Barberton, Ohio. |
| Diamond Alkali Co.,<br>Oliver Building,<br>Pittsburgh, Pa. | Fairport, Ohio. |
| Mathieson Alkali Works, Inc.,<br>60 East 42nd Street,<br>New York, N. Y. | Saltville, Va., and Lake Charles, La. |
| Michigan Alkali Co.,<br>Ford Building,<br>Detroit, Mich. | Two plants at Wyandottte, Mich. |
| Solvay Process Co.,<br>represented by<br>Solvay Sales Corporation,<br>40 Rector St.,<br>New York, N. Y. | Syracuse, N. Y., Detroit, Mich., and Baton Rouge, La. |

## Manufactured Soda (Cont'd.)

### Ammonia-soda process

| Name and address | Plant site |
|---|---|
| Southern Alkali Corporation,<br>Corpus Christi, Tex. | Corpus Christi, Tex. |

### Electrolytic process

| Name and address | Plant site |
|---|---|
| West Virginia Pulp & Paper Co.,<br>230 Park Avenue,<br>New York, N. Y. | Tyrone, Pa., Covington, Va.,<br>and Luke, Md. |